

Recent LSP Modeling of Omega Experiments*

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Kinetic plasma effects were successfully modeled in our hybrid (fluid electron-kinetic ions) simulations for two series of capsule implosion experiments at LLE¹

- First part of the simulation was carried out in Hydra² (an ICF rad-hydro code) in spherical one-dimensional geometry to 0.6ns until the end of the laser pulse.
- The capsule materials (shell and gas) conditions (densities, temperatures, velocities and ionization states) from Hydra at 0.6ns are initialized in LSP³ which is a particle-in-cell code capable of simulating implosion dynamics in spherical coordinates including particle collisions and fusion reactions.
- LSP has implicit solvers for Maxwell's equations and hybrid – fluid and particle species capabilities to treat disparate spatial and temporal physics phenomena.
- Our hybrid simulations show during implosion shock dynamics, ion species separation, preferential shock heating of heavy ion species, interpenetration of fuel and shell materials, electric fields associated with shock fronts and density gradients, DT neutron yields, fusion reaction rates, and fusion reaction bang time and width.

1. H. W. Herrmann, et al., Phys. Plasmas Vol. 16, 056312 (2009)
2. M.M. Marinak, et al., Phys. Plasmas Vol. 8, No.5, p2275 (May 2001).
3. <http://www.lspsuite.com/index.html>

Omega DTRat07 shots 47877 and 47878

Target: Hoppe glass (SiO_2) with inner diameter of $1094\mu\text{m}$, $\Delta_{\text{thickness}} = 4.7\mu\text{m}$,
Pressure fill 5.0 atm with equal atomic fractions of D and T (shot 47877)
Pressure fill 10.5 atm with atomic fractions D (32%), T(32%), ${}^3\text{He}(36\%)$ (shot 47878)

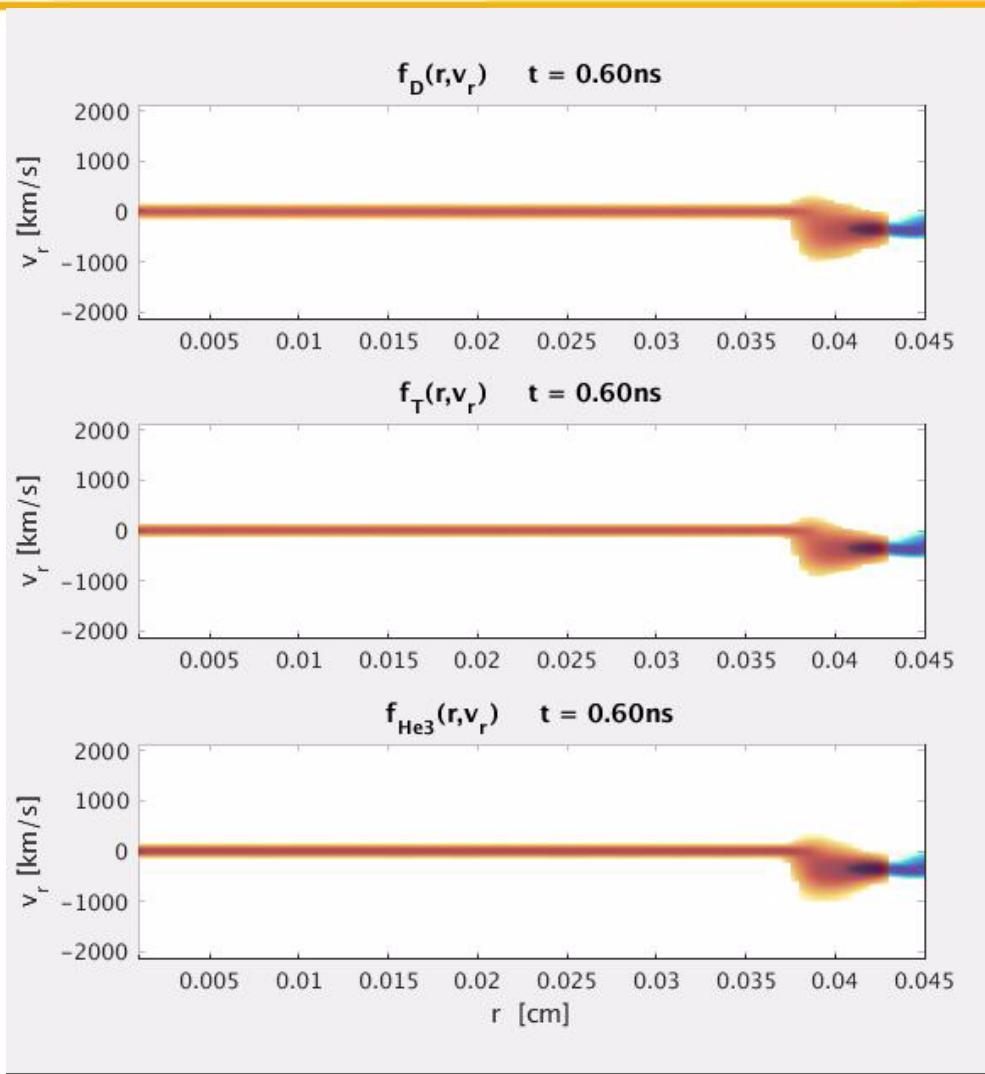
Laser beam: 60 beams, square pulse with width of 0.6ns and energy of 16.3kJ.

LSP simulation: Fluid electrons, kinetic ions – D, T, ${}^3\text{He}$, SiO_2

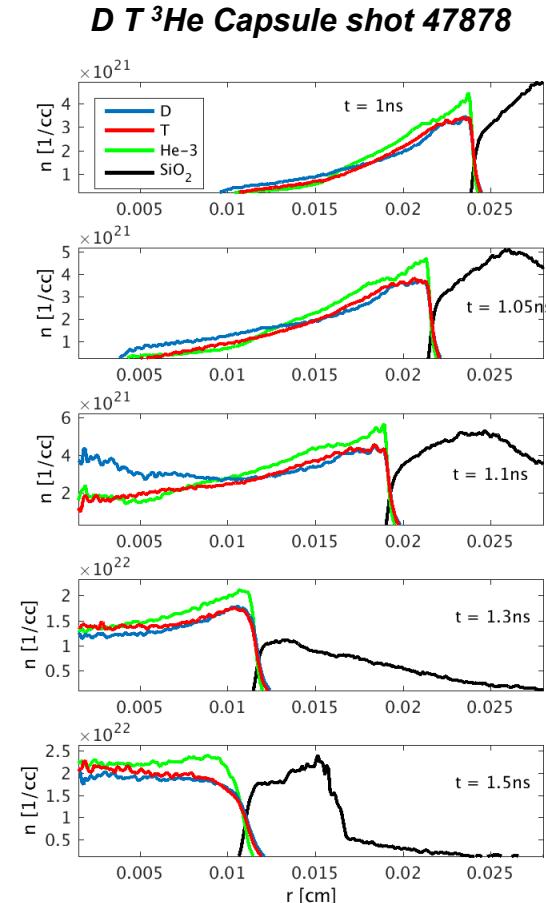
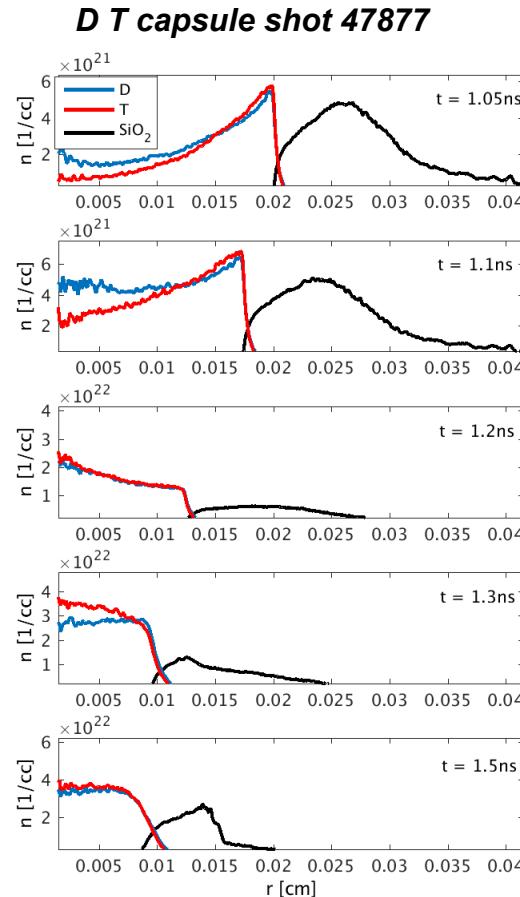
- One dimensional spherical geometry: $R_{\min} = 3 \times 10^{-4} \text{ cm}$, $R_{\max} = 0.1 \text{ cm}$.
- Number of cells = 1000 with cell size of $1.0 \mu\text{m}$ in our LSP simulation.
- Capsule initial conditions (electron and ion densities, temperature, flow velocities) were set up according Hydra simulation at 0.6ns.
- SiO_2 ions were modelled with averaged ion technique with atomic weight of 20 and average ionization of 10 from Hydra.
- DT or $\text{DT}{}^3\text{He}$ gas region with $R_{\text{gas}} = 414\mu\text{m}$ at 0.6ns from Hydra (100 zones).
- DT or $\text{DT}{}^3\text{He}$ gas region in LSP simulation had 414 cells with 5000 D, T, and ${}^3\text{He}$ ions per cell; 5000 SiO_2 per cell for the remaining cells.
- Over 9 million computational ion particles in the LSP simulation.
- Fusion events in LSP: D-D with two branches, and D-T. No T-T, D- ${}^3\text{He}$ reactions in standard version of LSP. All charged particles are tracked in the simulations.

Temporal evolution of ion phase space shows thermalization after bang time

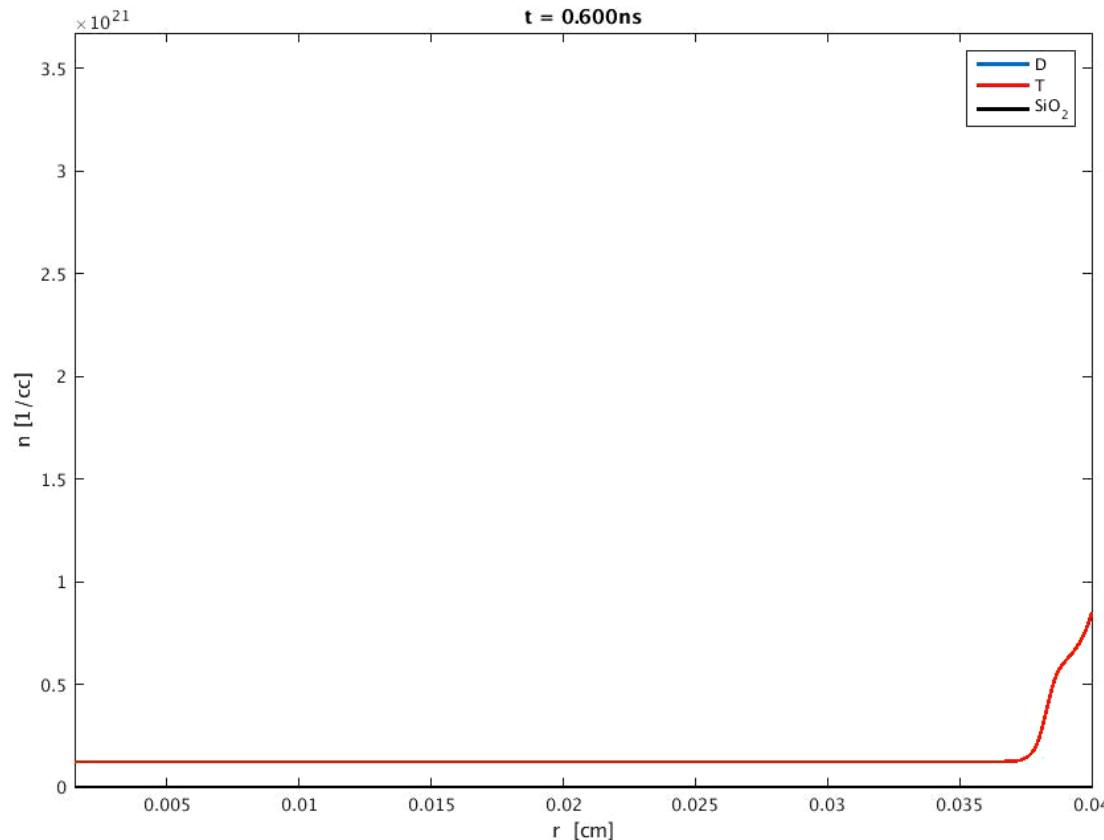
D T 3 He Capsule shot 47878



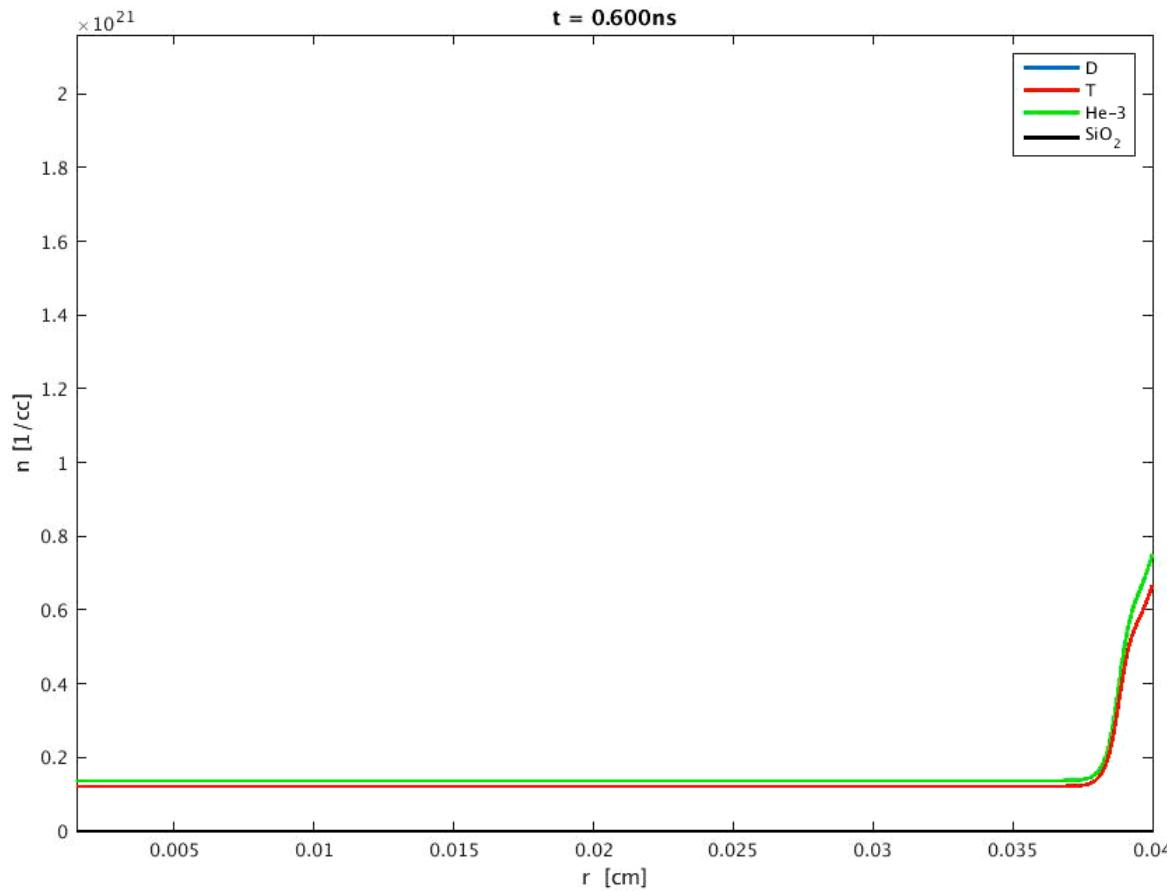
Density profiles over time show species separation and fuel-shell mixing during implosion



Density profiles over time show species separation and fuel-shell mixing during implosion

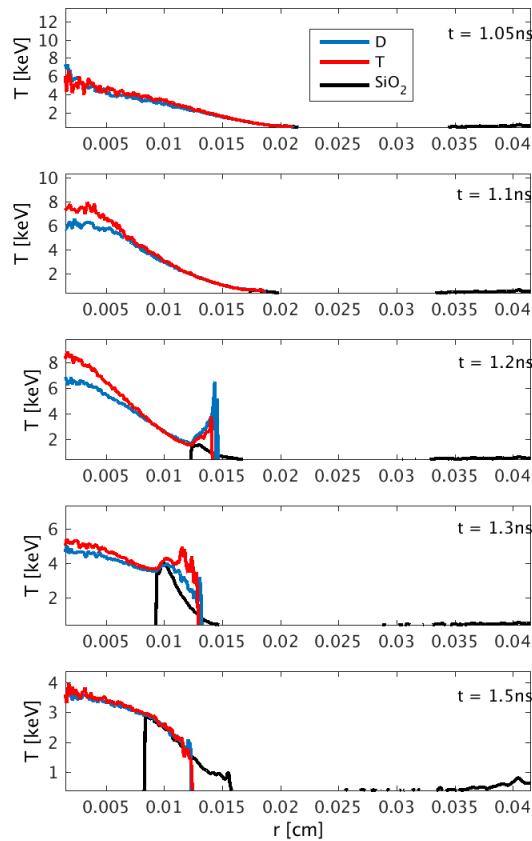


Density profiles over time show species separation and fuel-shell mixing during implosion

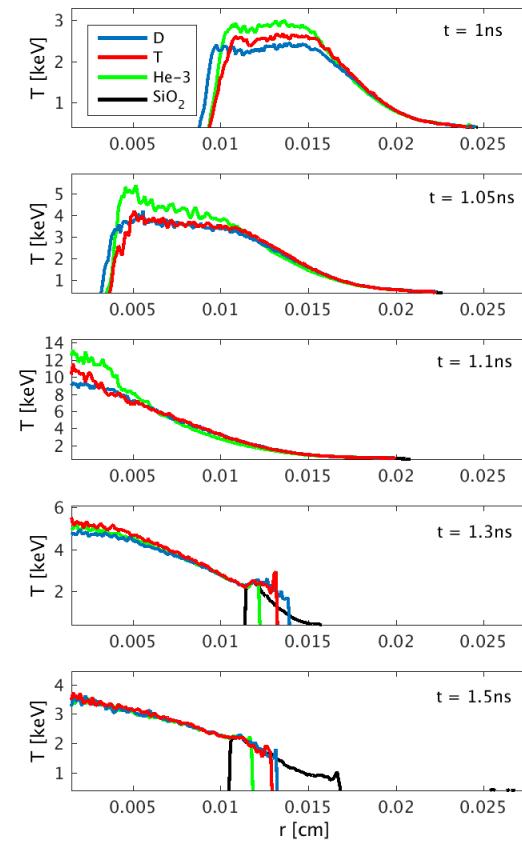


Triton and ^3He temperature profiles show more efficient shock heating during implosion. The radii of the hot spots are about $70\mu\text{m}$ and $105\mu\text{m}$

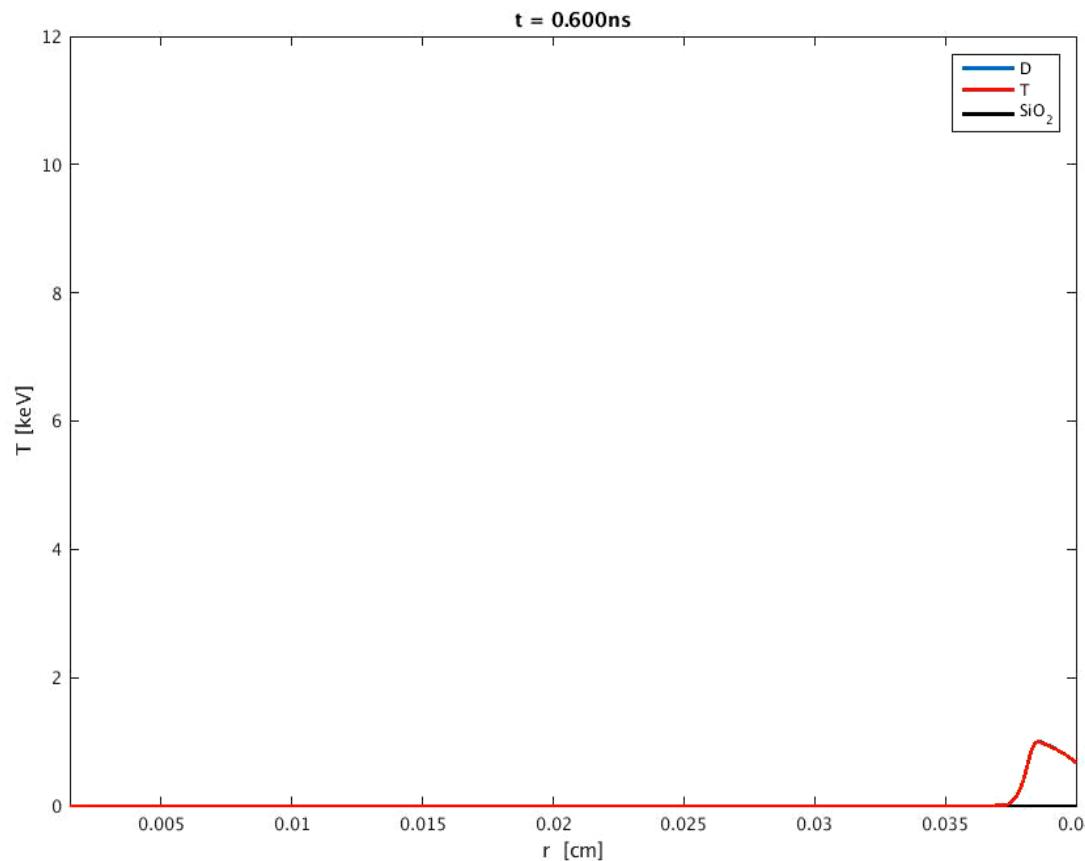
D T capsule shot 47877



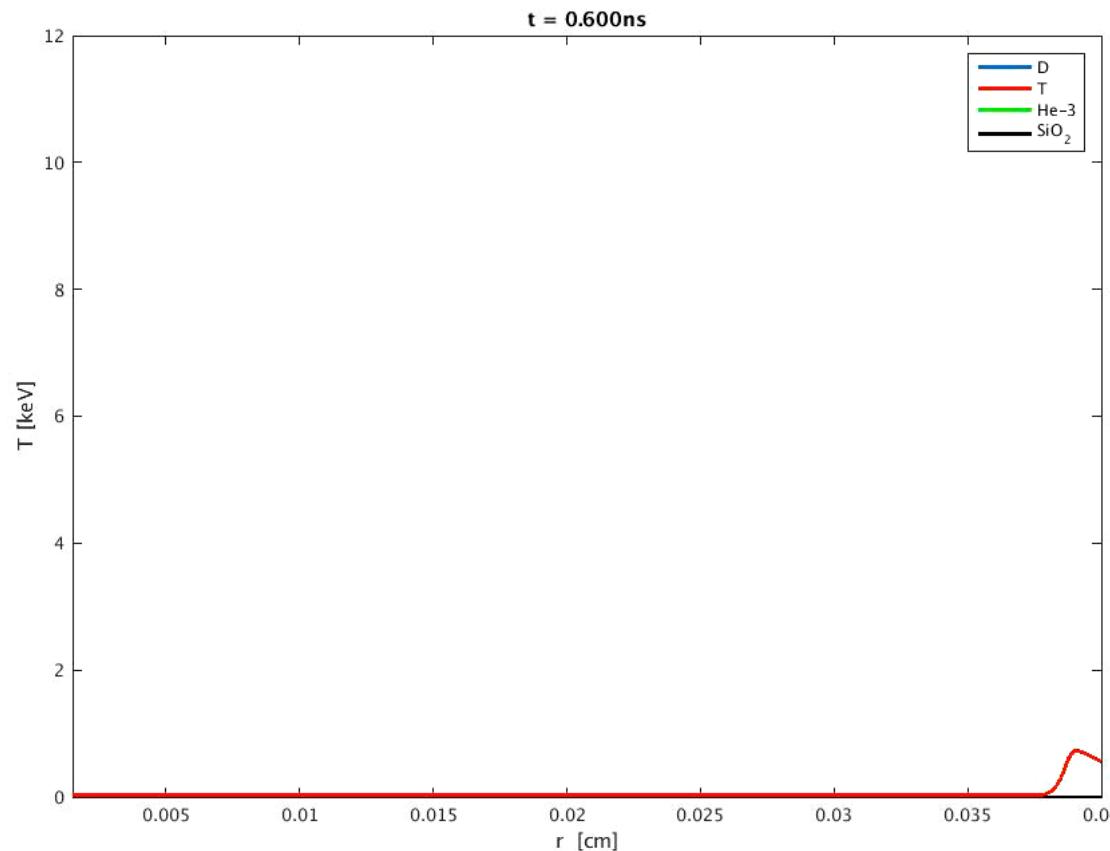
D T ^3He Capsule shot 47878



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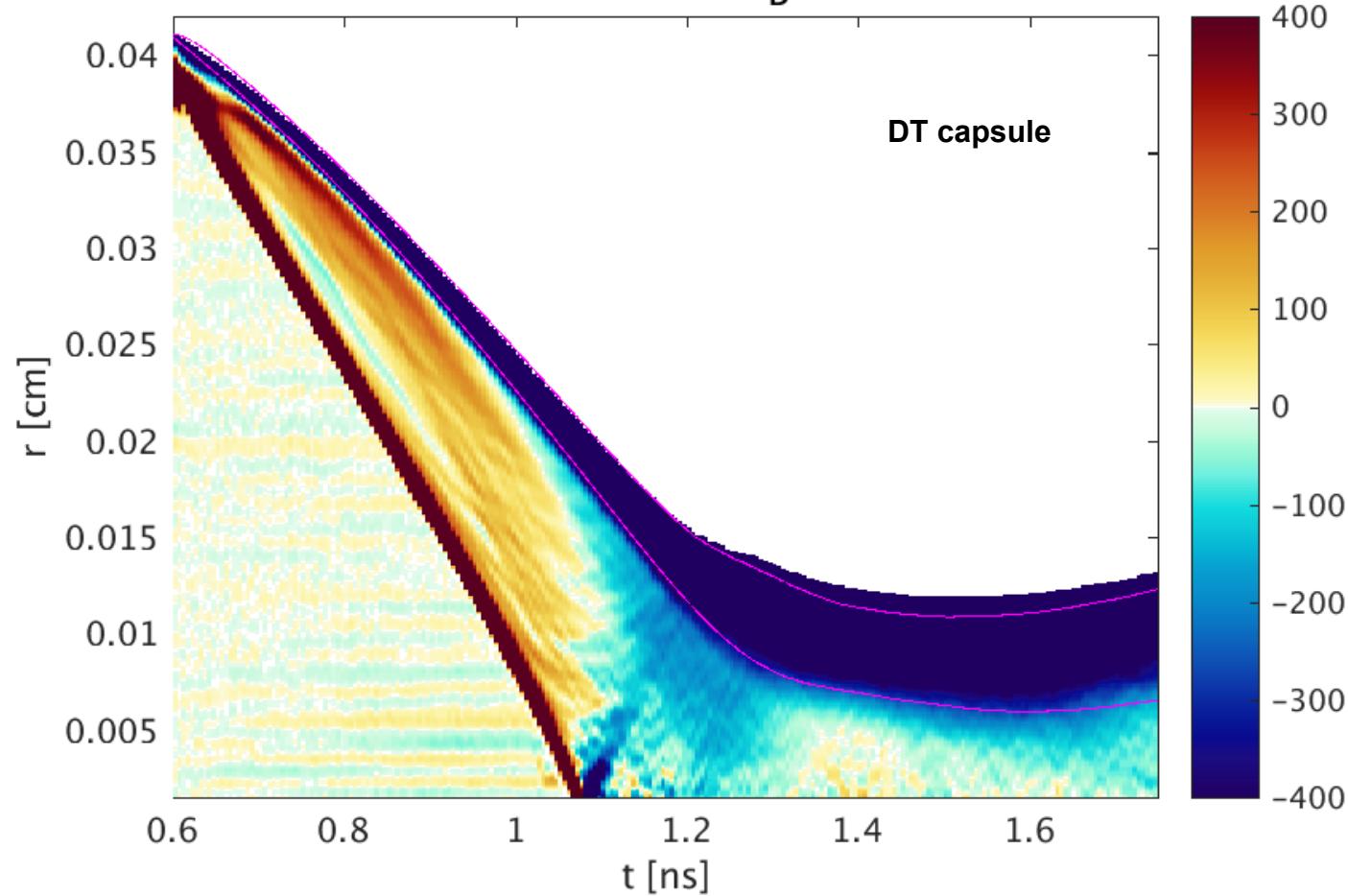
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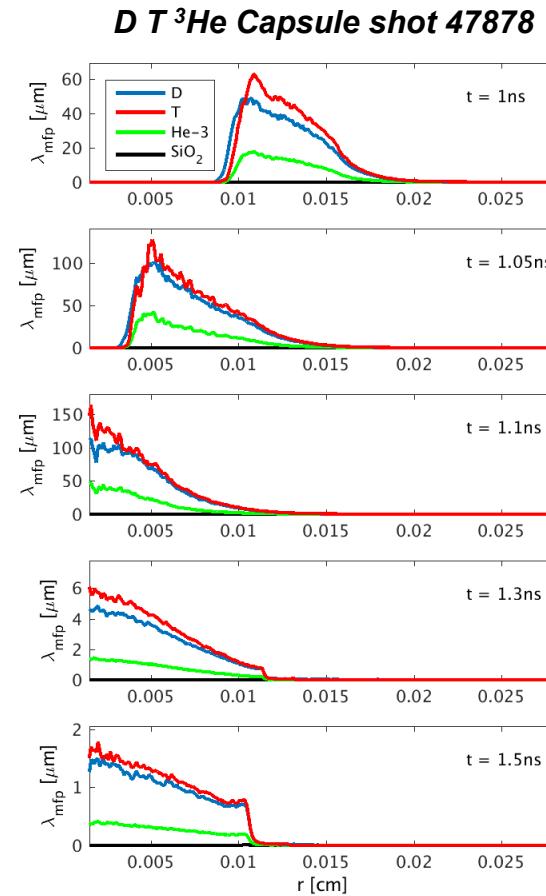
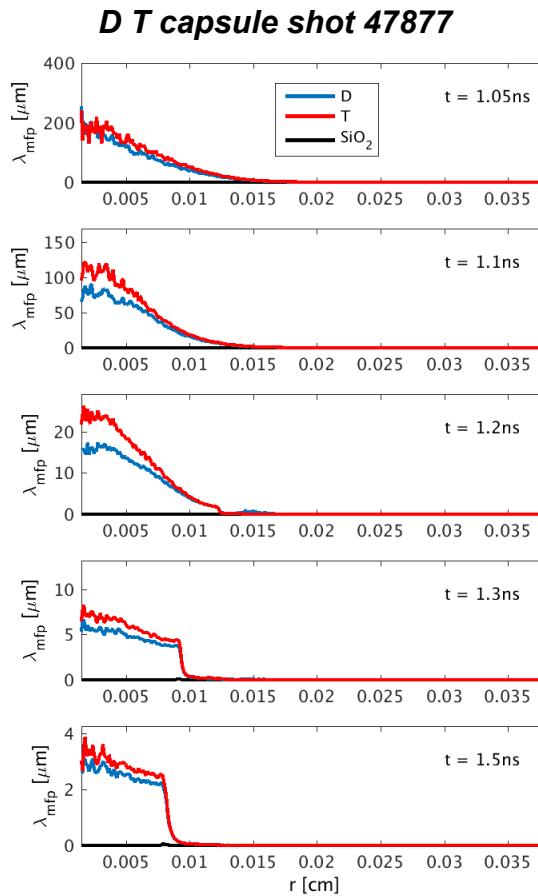
Our simulation shows incoming shock converges at about 1.07ns and the rebounding shock is generated

D T capsule shot 47877

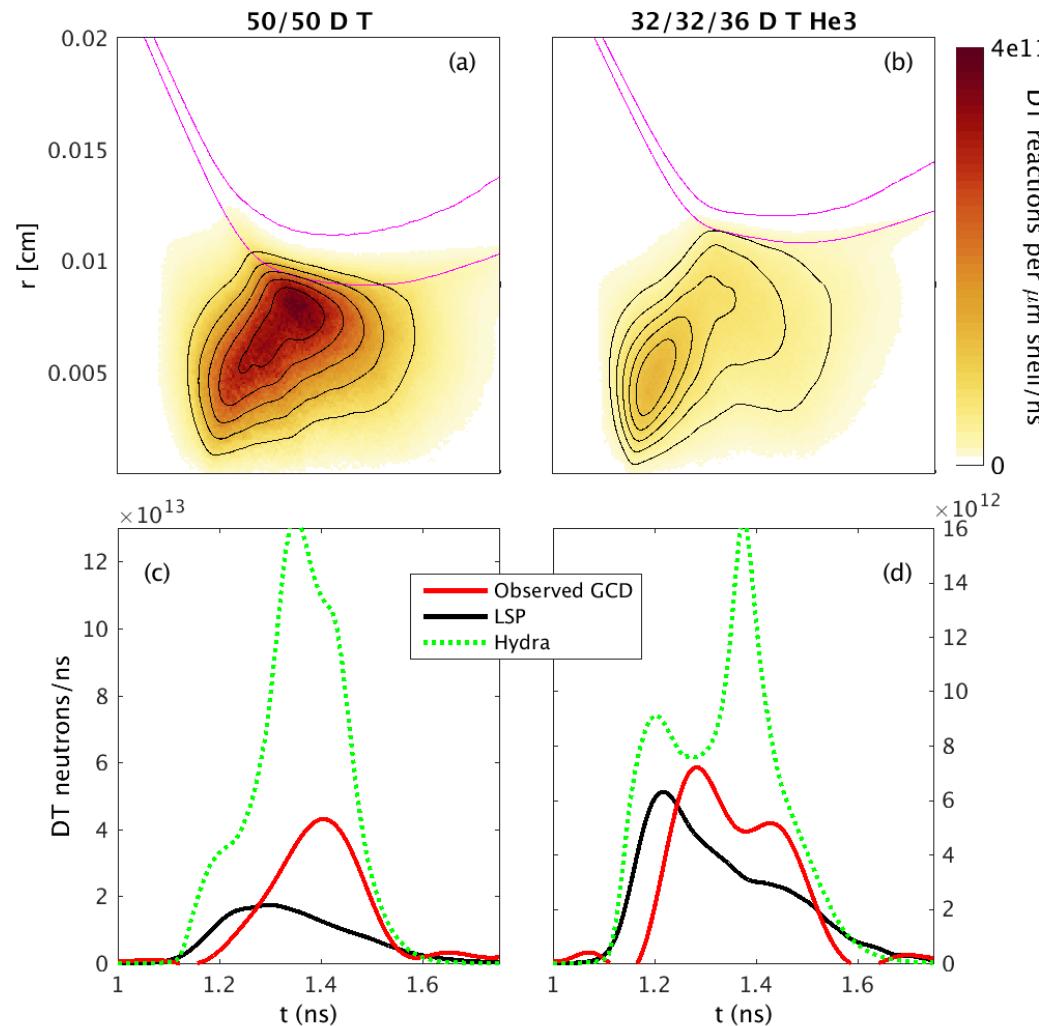
Pressure Scale ($1/p$) (dp_D/dr) [1/cm]



Mean free paths of fuel ions calculated from local temperatures and densities result in Knudsen numbers ~1 during shock convergence and << 1 at bang time

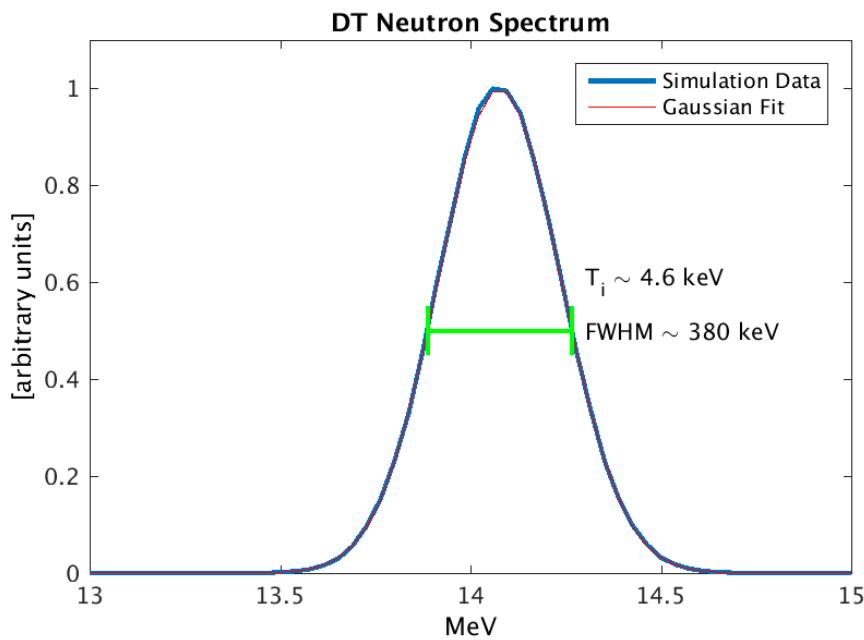


DT reaction rates calculated from $n_d n_t \langle \sigma v \rangle$ show the onset, location and intensity of DT burn. Burn rates agree reasonably well with measurements



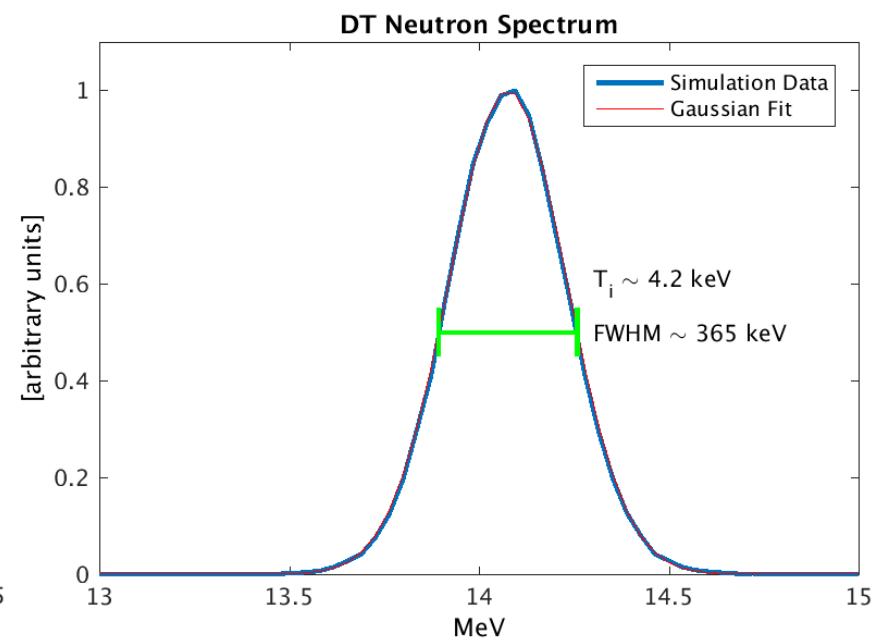
DT neutron spectra from our simulations and the burn weighted ion temperatures for the two shots

D T capsule shot 47877



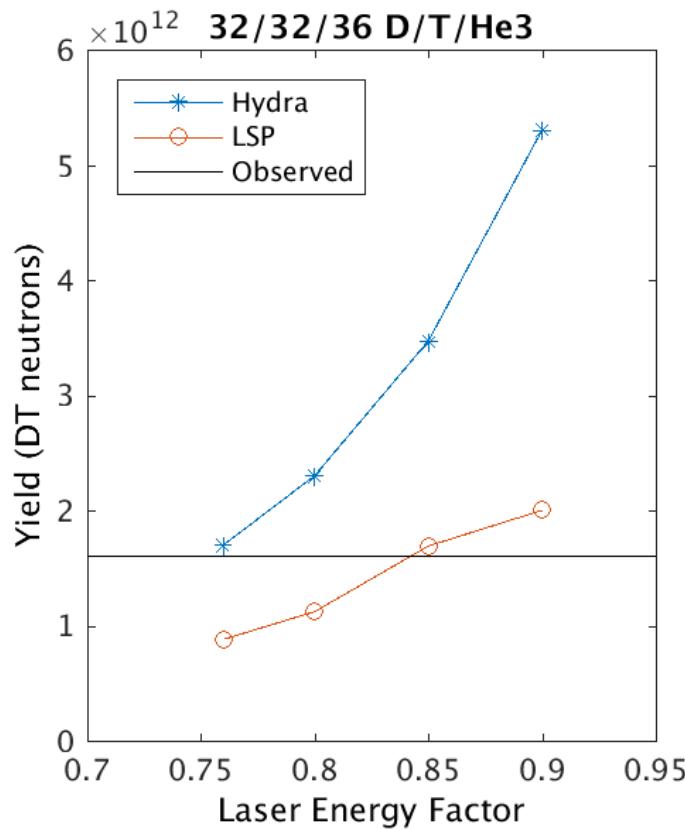
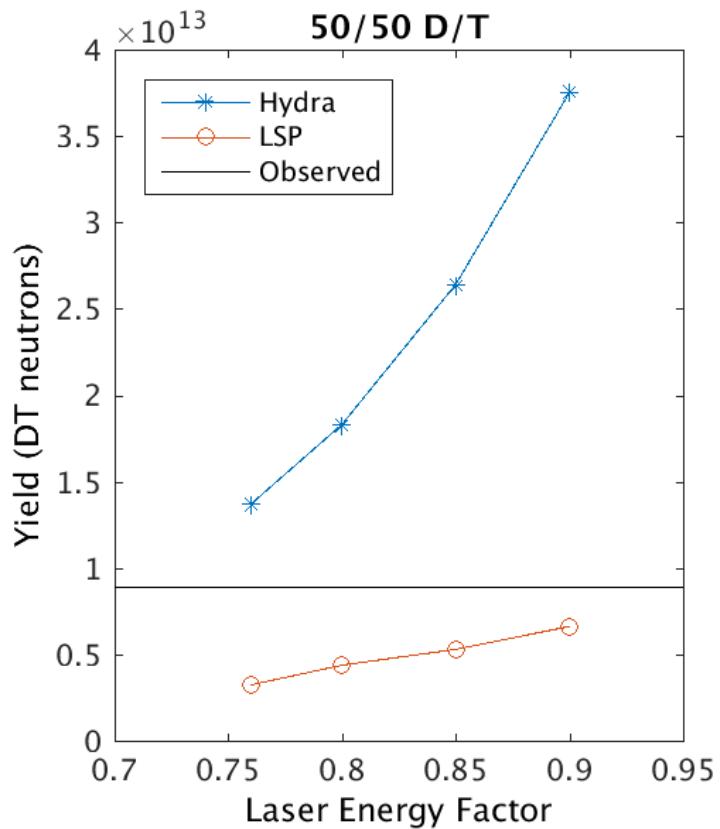
Data – 5.06 keV; Hydra – 5.17 keV

D T ^3He Capsule shot 47878



Data – 4.88 keV; Hydra – 3.94 keV

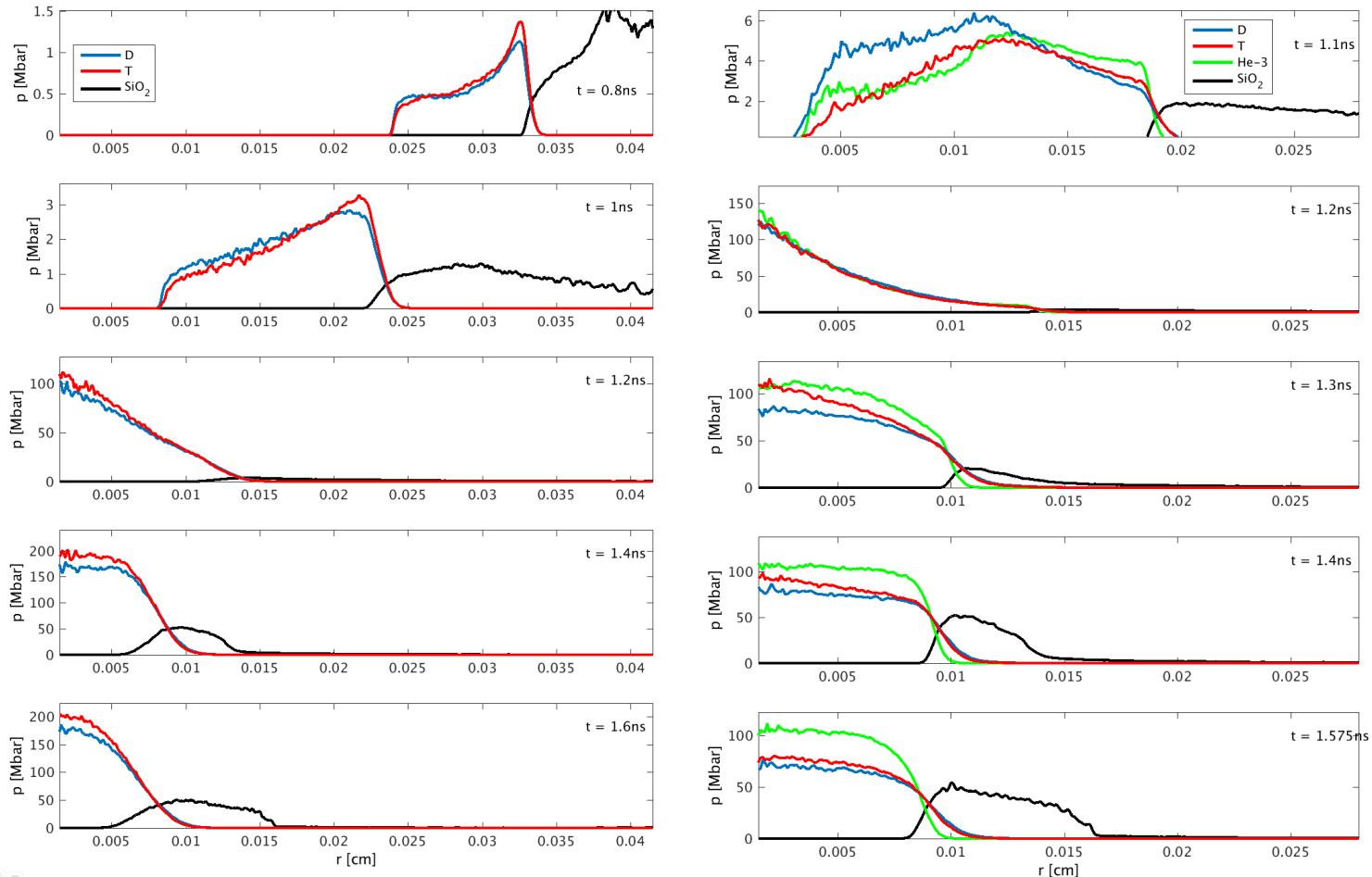
LSP simulation, Omega experiment, and Hydra calculation showed reasonable agreement



Summary

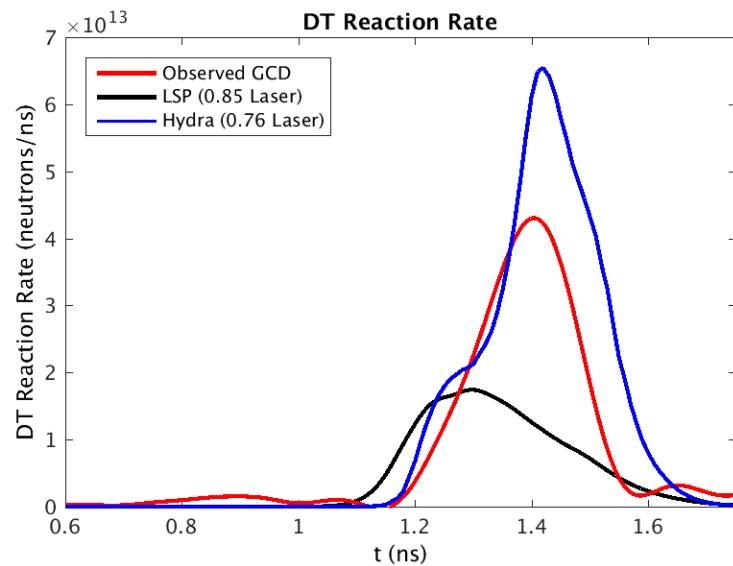
- We have successfully carried out hybrid simulations (fluid electrons and kinetic ions) for the implosion experiments conducted at Omega laser facility to investigate kinetic plasma effects.
- Kinetic effects such as species separation, diffusion across species interfaces, fuel tail depletion, thermalization of fuel after bang time, and others were observed in our simulations.
- Results from experiments, kinetic simulations and rad-hydro calculation show qualitatively reasonable comparisons.

Pressure profiles of D and T at bang time show the radii of the hot spots to be about $70\mu\text{m}$ and $105\mu\text{m}$



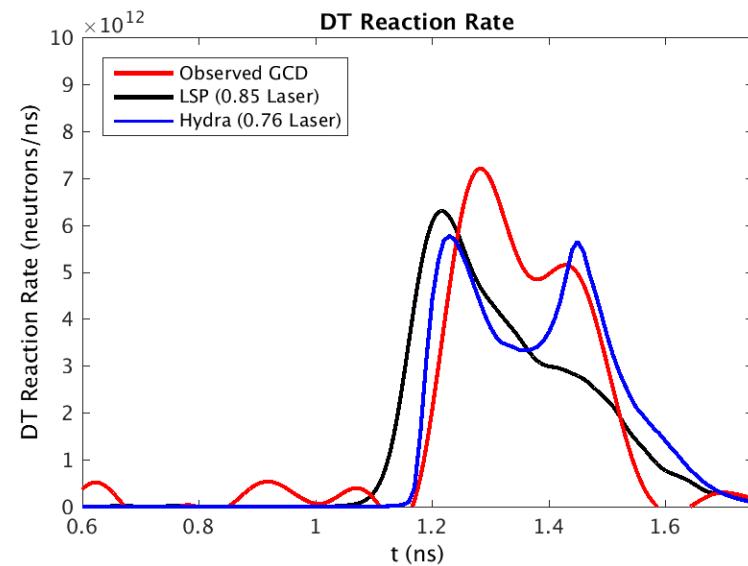
DT burn rates comparison among LSP, Hydra, and data

D T capsule shot 47877



Bang time:
Data: 1.40ns
LSP: 1.30ns
Hydra: 1.42ns

D T ^3He Capsule shot 47878



Bang time:
Data: 1.29ns
LSP: 1.22ns
Hydra: 1.23ns